

Tests of a Structure for Quasars

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Abstract. The model I recently proposed for the structure of quasars unifies all the emission, absorption and reflection phenomenology of quasars and AGN, and so is heavily overconstrained and readily tested.

Here I concentrate on how the model has performed against tests since publication - with many of the tests being reported at this meeting. I then begin to explore how these and future tests can discriminate between this wind model and 3 well-defined alternatives.

1. Introduction

Quasar research suffers from an overabundance of phenomenology. There has been a constant piling up of new details at all wavelengths with sadly little integration, let alone physical explanation. While this is fascinating for insiders, quasars have become an intimidating field for the general astronomer.

This is not a situation to despair of, because stars were in a similar situation for 20 years (Lawrence 1987). The spectroscopic definitions of the stellar types (O B A F G K M) read quite similarly to those of AGN classifications (e.g. G stars: “CaII strong; Fe and other metals strong; H weaker”, Allen 1975). We now know that the main sequence is a simple temperature progression, determined fundamentally by stellar mass. There is hope that the complexities of quasars will resolve themselves the same way. I have proposed (Elvis 2000) a geometrical and kinematic model for quasars that does seem to subsume a great deal of the phenomenology of quasar emission and absorption lines into a simple scheme.

Quasars, unlike stars, are not spherical. (We have known that axisymmetry is appropriate since the first double radio sources were discovered). This means that geometry matters, and when this is the case the physics cannot be worked out until we get the structure right: the solar system simply could not be solved in a Ptolemaic geometry. A normal sequence in constructing a physical theory is to work out the right geometry, then the kinematics and lastly the dynamics (c.f. Copernicus - Kepler - Newton). In quasars instead, I believe that the physics has largely already been worked out, but discarded because the geometry was not in place, making the physics appear wrong.

Here I briefly outline the model and then concentrate on tests of the model, many reported at this meeting. A model needs a rival if the tests are to be strong, so I have also begun to explore alternative wind geometries to see how they differ from my model.

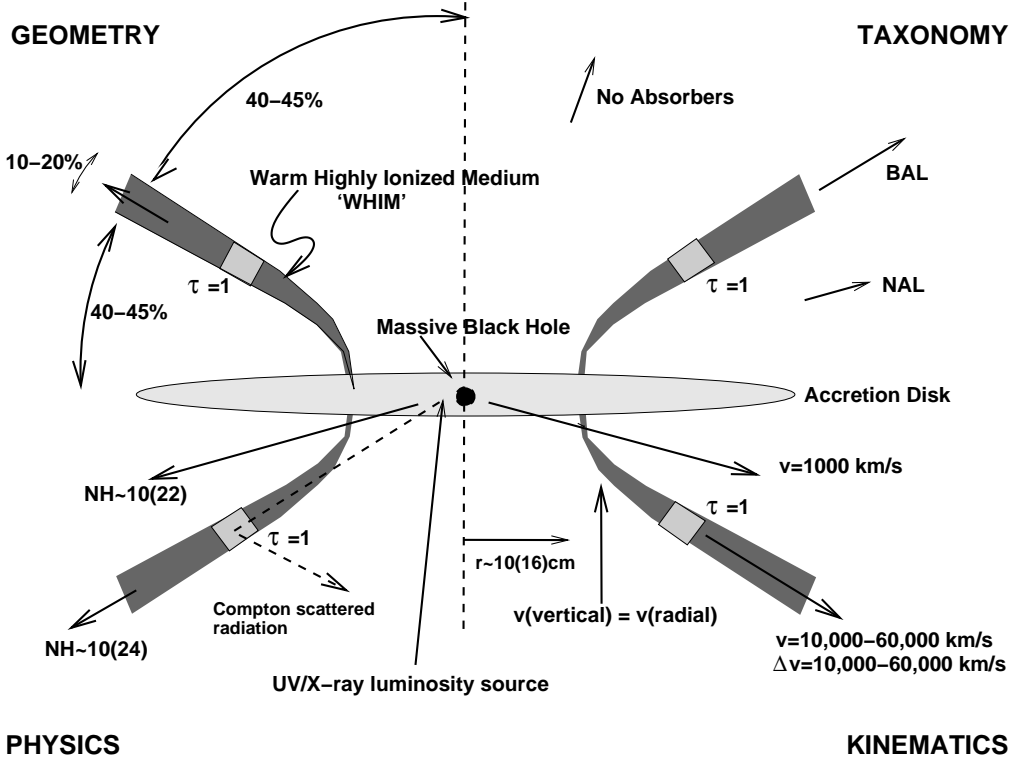


Figure 1. A Structure for Quasars

2. A Structure for Quasars

In Elvis (2000) I proposed that a flow of warm ($\sim 10^6 \text{K}$) gas rises vertically from a *narrow range of radii* on an accretion disk. This flow then accelerates, angling outward (most likely under the influence of radiation pressure from the intense quasar continuum) until it forms thin conical wind moving radially (figure 1). When the continuum source is viewed through this wind it shows narrow absorption lines (NALs) in both UV and X-ray (the X-ray ‘warm absorber’); when viewed down the radial flow the absorption is stronger and is seen over a large range of velocities down to $v(\text{vertical})$, the ‘detachment velocity’, so forming the Broad Absorption Line quasars. Given the narrowness of the vertical flow ($\sim 0.1r$), the divergence of the continuum radiation at the turning point will be $\sim 6^\circ$, giving 10% solid angle coverage, and so the correct fraction of BAL quasars. [The angle to the disk axis, 60° , is at present arbitrarily chosen to give the correct number of NAL and non-NAL quasars.]

This ‘Warm Highly Ionized Medium’ (WHIM) has a cool phase (like the ISM) with which it is in pressure equilibrium. This cool phase provides the clouds that emit the Broad Emission Lines (BELs). Since the BEL clouds move along with the WHIM they are not ripped apart by shear forces; and since the medium is only Compton thick along the radial flow direction rapid continuum variations are not smeared out. Both problems had long been a strong objections to pressure confined BEL clouds, but they are invalid in the proposed geometry.

The radial flow is Compton thick along the flow direction, and so will scatter all wavelengths passing along that direction. Since the flow is highly non-spherical the scattered radiation will be polarized. The solid angle covered by the radial flow is 10%-20%, so this fraction of all the continuum radiation will be scattered, leading to the filling in of the BAL troughs, and to an X-ray Compton hump in all AGN. Since the WHIM is only ionized to FeXVII, there will be Fe-K fluorescence off the same structure at ~ 100 eV EW. Some of the BEL radiation will also pass along the flow and will be scattered off the fast moving flow, producing the polarized, non-variable ‘Very Broad Line Region’.

3. Tests of the Model

The model makes five main claims. Each one has been tested already and passed, and each can be tested further:

Claim 1: The quasar wind is a warm, highly ionized medium (WHIM). The velocities of the UV absorption line systems must match X-ray absorbers. In NGC3783 (Kaspi, these proceedings) and NGC4051 (Collinge et al., 2001) they do match. The line strengths must also be consistent across the X-ray and UV lines. In NGC3783 (Kaspi, these proceedings) they also match, if a particular EUV spectral slope is assumed. This slope is tightly constrained, which implies an accurate thermometer for the, otherwise hard to observe but energetically important, EUV continuum. Consistency with the NLR optical coronal lines is required. Accretion disk models predict specific EUV continuum shapes, which will be stringently tested if the X-ray/UV absorbers are the same.

Claim 2: BAL medium = NAL medium = WHIM. Since Compton scattering is wavelength independent the BAL covering factor in the soft X-ray band should be the same as in the optical. Partial covering of the right order is seen in the X-ray spectrum of one BAL quasar (Mathur, these proceedings). The low energy X-rays should be polarized like the optical BAL troughs, and have consistent fluxes.

Claim 3: WHIM = BELR Confining Medium. Everett (these proceedings) gave good arguments for a 2-phase medium in quasar winds, although in a different context. The high ionization BELs (PVII, NeVIII) at $\sim 770\text{\AA}$ (rest) seen in some high redshift quasars (Hamann et al. 1995) could arise from the WHIM. In this case they should match the WHIM properties. In fact they do, with column densities of $\sim 10^{22}\text{cm}^{-2}$, a temperature of $5 \times 10^5\text{K}$ (if collisional), and a covering factor of 0.5 (and unlike the BELR for which 0.1 is a typical value). The radius of the NAL from the continuum source has to match the radius of the high ionization BELR. In NGC 5548 this works, but the NAL radius is poorly constrained (a factor 100). Short recombination times, which will determine the NAL density, are the key to a better constraint on the radius. Timescales of hours are likely, and require quite large continuum variations on this timescale or less to be measurable.

Claim 4: Narrow Range of radii: cylindrical WHIM/BELR. Arav (these proceedings) shows that the covering factor or the NAL systems in NGC 5548 varies systematically with velocity in a way that is easily understood as a narrow flow of material across our line of sight. These constraints will determine

many parameters of the flow (thickness, angles, density contrast, acceleration rate).

Cohen (these proceedings) explains the rotation of polarization position angle of $H\alpha$ in some radio galaxies by means of a rotating circularly symmetric structure, a disk or cylinder, which emits the BELs and scatters BEL photons off the opposite sides. A few percent of the $H\alpha$ photons are polarized and red or blue shifted according to where they strike the opposite face. A WHIM shaped cylinder is hollow, making it simple for photons to cross to the other side. Similar PA rotations are implied for *all* edge-on AGN, i.e. those with NALs.

Laor (these proceedings) showed that weak $EW([OIII])$, the presence of NALs, and broad CIV are correlated. If $[OIII]$ is isotropic and the continuum is from a disk then the $EW([OIII])$ is an inclination indicator, so these effects are qualitatively predicted by the proposed structure.

Murray (comments at this meeting) notes that following a flare the BELs may become optically thin, revealing a double-peaked profile for a cylinder or disk geometry. He finds just such an effect in the NGC 5548 data base.

Claim 5: Reflection from Structure. Compton scattering off the radial part of the structure must produce a symmetric X-ray 6.4 keV Fe-K emission line with a width broader but comparable to the BELR widths. Since the WHIM is optically thin to Fe-K, while BEL clouds are optically thick, the two profiles will be different, with Fe-K possibly showing a double peaked structure. This needs detailed calculations, since it can be measured with Chandra grating spectra.

The Fe-K emission line will respond to continuum changes with a smeared response determined by the size of the $\tau=1$ scattering ring. Takashi, Inoue & Dotani (2001) have found such an effect in NGC 4151, and derive an Fe-K scattering region size of 10^{17} cm. This is a few times larger than the CIV radius for NGC 4151 (9 ± 2 light-days, 2×10^{16} cm, Kaspi et al. 1996), consistent with our structure, but is strongly inconsistent with an accretion disk or pc-scale torus origin.

At any given angle there will be four dominant delay times relative to a central continuum flaring event, as the flare scatters off the near and far parts of the $\tau=1$ rings above and below the disk plane. (The disk may obscure one or both parts of the lower ring.) These should show up in autocorrelation functions of the continuum at low amplitudes. Schild (1996, 2001) has found autocorrelation timescales in the gravitational lens Q0957+561 and shows them to be consistent with the double ring expected from this structure.

The X-ray ‘Compton Hump’ should show the same time smearing and delays as the Fe-K line. Moreover the Compton Hump should be polarized, just as the optical BAL troughs are polarized.

4. Alternative Wind Models

To reconcile the presence of both a fast (BAL) wind and a slow (NAL) wind in most AGN and quasars, we adopted a single wind with a specific geometry. It is worth considering alternative means of reconciling these, relaxing the constraint that they are the same flow. There are two main possibilities: either high luminosity objects have faster winds, or faster winds are emitted in some preferential direction, and slower winds in others. Here we take a first look at

these options. We assume that the models retain all the other features of our model. I.e. they still try to combine the UV and X-ray absorbers in a single WHIM (our starting point); and they have the BEL clouds embedded in this wind; they try to explain reflection features via scattering off the fast wind.

4.1. Luminosity Dependent Velocities

In this hypothesis the fast BAL winds are emitted only by high luminosity quasars (into a $\sim 10\%$ solid angle), while NAL winds are found only at lower luminosities (for a $\sim 50\%$ solid angle). The wind no longer needs to arise from a narrow range of disk radii. There are a number of comments that can be made:

(1) In this scenario a continuum of widths should be found with a covering factor that decreases from $\sim 50\%$ at NGC 5548 luminosities ($L_X \sim 5 \times 10^{43} \text{ erg s}^{-1}$, Elvis et al., 1978), to $\sim 10\%$ $L_X \sim 10^{46} \text{ erg s}^{-1}$ PHL 5200, Mathur, Elvis, & Singh 1995). There is a range of BAL velocities, but a line width vs. luminosity or covering factor analysis has not yet been performed.

(2) This model has a built-in explanation for the absence of low luminosity BALs; our model requires low luminosity AGN to be dustier.

(3) If the BELs are embedded in the fast BAL wind then they should have similar profiles, with no obvious physical cause for a ‘detachment velocity’.

(4) Can high ionization BELs with large covering factor arise in this model?

(5) The scattering effects of the radial part of the wind (X-ray Fe-K emission line, Compton hump, optical polarized flux) will disappear in lower luminosity objects since the column density needed to produce scattering is much larger than the column density through the X-ray warm absorbers, and low luminosity AGN will have no fast wind out of the line of sight to produce the polarized, non-variable ‘Very Broad Line Region’. The opposite is observed (Iwasawa & Taniguchi 1993).

(6) The BAL opening angle of 10% does not arise naturally from the narrow width of the wind origin site on the disk.

(7) Are there directions in which one looks through the wind? If so then NALs will be seen, the wind originates from a restricted range of radii and the picture reverts to something close to our model.

The absence of reflection effects in this version considerably weakens its unifying power.

4.2. Orientation Dependent Velocities

In this hypothesis the quasar wind has fast (BAL) velocities only in some directions (covering $\sim 10\%$ solid angle), and has slower (NAL) velocities in other directions (covering $\sim 50\%$ solid angle). There are two obvious preferential directions for the fast wind: *polar* and *equatorial*. Some comments are:

(1) Proga (these proceedings) finds such a directional velocity stratification arising naturally from his simulations, with higher velocities toward the pole.

(2) Like our model, this hypothesis does not explain the absence of low luminosity BALs without invoking dust.

(3) Compton scattering features will arise naturally in all objects in this model, as in ours, if the fast wind has sufficient column density.

(4) The fast wind has to have a large column density of high velocity material when viewed end-on to reproduce the BAL observations. This arises naturally

in our model, but is not obvious in this hypothesis. A large column density implies a large mass input rate at the wind base, decaying rapidly to larger radii (in the fast polar case; to smaller radii for the fast equatorial case).

(5) In the fast polar case a much ($<1\%$) lower column density is required when viewed from other directions to avoid BALs being seen more often. A long thin BAL region is necessary, which would have to be non-divergent to maintain column density. This may make it difficult to cover a 10% solid angle. An equatorial fast wind avoids this problem.

(6) An equatorial fast wind has the faster material originating further from the continuum source, which seems unlikely since radiation pressure and Keplerian rotation both predict the opposite. A polar fast wind avoids this problem.

The difficulties in this version of the model lie primarily in theory: can the large column densities needed in the fast wind be produced, in an acceptable geometry? Neither the polar nor equatorial solution is fully appealing.

5. Conclusions

Because the model puts together so many aspects of quasar/AGN phenomenology it is highly overconstrained, and so readily tested. This is a strength of the model. Our model has passed quite a number of tests already, but they are not yet as stringent as one would like.

Quite simple extensions of the model (e.g. to type 2 objects, Risaliti, Elvis, & Nicastro 2001) suggest that much more of the quasar/AGN phenomenology can be incorporated with only a handful of extra variables. With luck then, quasars will now enter a period of rapid development of their physics (e.g. Nicastro 2000), allowing their physical evolution to be understood, and placing them constructively within cosmology.

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References

- Allen C.W. 1975, ‘Astrophysical Quantities’ 3rd ed. [London:Athlone], p. 198.
- Elvis M. 2000, ApJ, 545, 63. astro-ph/0008064
- Elvis M. et al. 1978, MNRAS, 183, 129
- Collinge M.J., et al., 2001, ApJ in press.
- Hamann F., Shields J., Ferland G., & Korista K. 1995, ApJ, 454, 688
- Iwasawa K. & Taniguchi Y., 1993, ApJL, 413, L15
- Kaspi S., et al. 1996, ApJ, 470, 336
- Lawrence A., 1987, PASP, 99, 309
- Mathur S., Elvis M., & Wilkes B.J., 1995, ApJ, 452, 230
- Mathur S., Elvis M., & Singh K.P., 1995, ApJL, 455, L9
- Schild R. 1996, ApJ, 464, 125
- Risaliti G., Elvis M. & Nicastro F. 2001, ApJ, submitted
- Takahashi T., Inoue H., & Dotani T., 2001
- Nicastro F., 2000, ApJ 530, L65